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Beryllium Dynamic Strength Measurements: Report on Task 2 Agreement #B590737

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Disclaimer

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BERYLLIUM DYNAMIC STRENGTH MEASUREMENTS

Report on Task 2
Agreement # B590737
between RFNC – VNIIEF (Russia) and LLNS (USA)

Head of works under Agreement

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Contents

Introduction

Goal of the work under Agreement #B590737 is development of experimentally justified model of beryllium shear strength of American production (*Be S200F*) in the pressure range of P~10÷50 GPa and strain rates up to $\dot{\varepsilon}_i \approx 10^5 \div 10^6$ s^{-1}. The *Be* shear strength models, which are available in this range of parameters, have no sufficiently reliable experimental justification.

Objective of this Task of Agreement #B590737 was demonstration of possibility to perform X-ray radiography recording of perturbation growth in *Be* in conditions of the R-T instability under quasi-isentropic loading of liners up to pressure P~40÷50 GPa and to perform quantitative measurements.

Besides, this report presents data on measurements of liner velocity growth pace where the liner is accelerated by explosion products of HE of the second stage from the two-stage explosive device [1], [2]. The velocity was measured with use of the laser interferometric technique. The obtained experimental data are used for correct calculation of pressure at the boundary of the investigated liner (*Be S200F*) during calibration of the strength model.

The following VNIIEF experts took part in this work: N.L. Boriskova, V.V. Burtsev, V.V. Gorbunov, V.V. Igonin, A.I. Lebedev, M.O. Lebedeva, V.A. Raevsky, A.N. Cheraev, V.V. Filyaev, M.A. Kaganov.

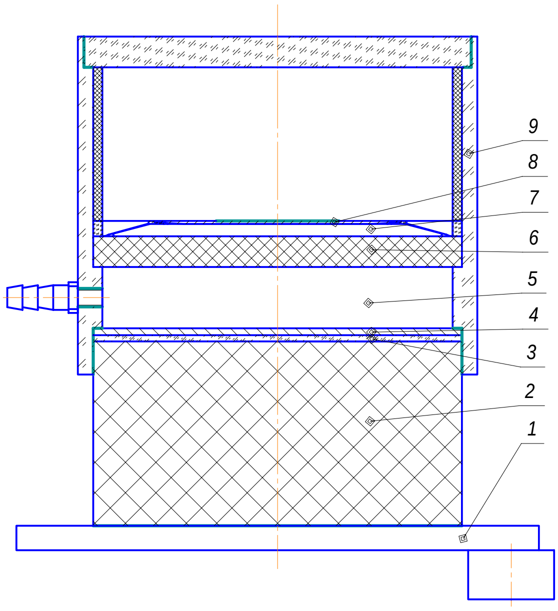
The report was translated by O.V. Myasoedov.

1 Demonstration of capabilities of X-ray radiography technique

1.1 Experimental assembly

To investigate shear strength of *S200F*-type *Be* by the perturbation method in the pressure range up to P~40÷50 GPa and strain rates up to $\dot{\varepsilon}\sim 10^5\div 10^6$ s^{-1}, it is suggested to use the experimental assembly, which was earlier used in work [1]. Scheme of the assembly is presented in Fig. 1.1.

In the tests, we use HE with caloricity Q=6.1 kJ/g and total weight M~1.15 kg.



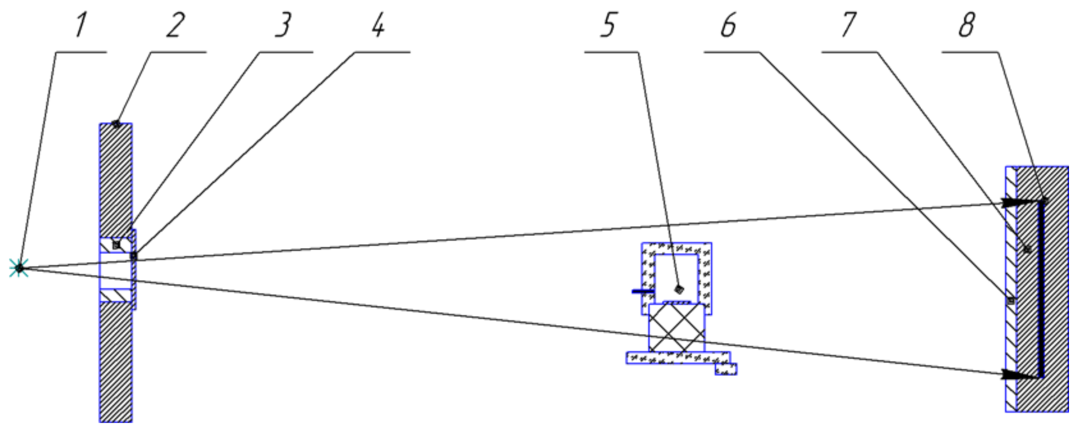
1 - generator of planar shock wave;
2 - HE of first stage: ∅90×80 mm;
3 - damper: plexiglass, ∅90×2 mm;
4 - impactor of first stage: *Fe*, ∅90×2.2 mm;
5 - vacuumized gap: δ=10 mm;
6 - HE of second stage: ∅90×10 mm;
7 - vacuumized gap: δ=2 mm;
8 - studied liner: *Be*, ∅50×2 mm;
9 - sealing cylinder.

Fig. 1.1 – Two-stage loading device for quasi-isentropic loading of *Be* liner. P~40÷50 GPa

X-ray radiography recording is performed for the liner flight base, which does not exceed S~10÷12 mm (t~2 μs). At this time, the *Be* liner gets velocity U~7 km/s.

1.2 X-ray radiography technique

Fig. 1.2 presents the scheme of test conduction, which was earlier used in work [3].



1 – source of X-ray radiation;
2 – element of armored protection of bunker;
3 – collimator;
4 – protective screen (*Al*);
5 – experimental assembly;
6 – protective screen (*Al*);
7 – armored cassette;
8 – screens ADC – CR (10 units).

Fig. 1.2 – Scheme for conduction of tests

Facility «Eridan-3» is the source of X-ray radiation. Its boundary radiation energy is 1 MeV, pulse duration at half-height is ~0.1 μs. The X-ray facility has capability of operation in the two-frame regime of X-ray radiography. As anodes (radiation sources) of the X-ray facility 2, which is Eridan-3, tantalum needles with the diameter of ~2 mm are used. In the tests, the magnification factor is K~1.1÷1.3.

X-ray image is recorded in a package of photochromic screens ADC - CR [4]. Application of photochromic screens ***in a package*** allows improving quantum efficiency (sensitivity) of the recording system. Images, which are received in the screens, are summarized by special algorithm [4]. Mathematic processing of the images is performed by the package of programs [5], [6].

The advantages of the photochromic screens, as compared to X-ray film traditional for these investigations, are the following: a wide dynamic range of recording, linear transfer characteristic in large range of absorbed dose, one-quantum gamma-sensitivity of the active substance luminophor. Use of these screens allows resolving objects with the difference of optic thickness of ~0.02÷0.05 g/cm^2.

The peculiarity of the tests with recording the perturbation growth in beryllium is small difference in densities of explosion products (ρ~1.88 g/cm^3 in unreacted state, up to ρ~2.6 g/cm^3 in overcompressed state) and *Be* (ρ~1.85 g/cm^3). Density of the investigated materials *Cu* (ρ~8.93 g/cm^3), *Ta* (ρ~16.6 g/cm^3) exceeded significantly the explosion product density in the earlier performed investigations by the perturbation method. It caused contrast at boundary of the liners.

Fig. 1.3 presents a two-frame X-ray film of perturbation growth in *Be*.

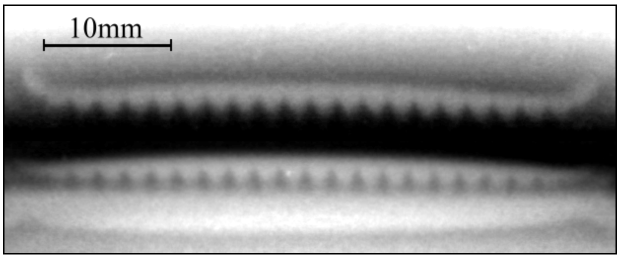


Fig. 1.3 - Two-frame X-ray film

The test was performed with a collimator, which had a circular aperture with the diameter of 50 mm, with tantalum radiation sources having the diameter of 2 mm and protective aluminum screens having the total thickness of 5 mm. The flight bases and perturbation amplitudes were the following: S_1=3.4±0.3 mm, A^1=1.3±0.1 mm, S_2=10.3±0.3 mm, A^1=1.5±0.1 mm.

Therefore, the possibility was demonstrated for performing two-frame recording of perturbation growth at quasi-isentropic loading of *Be* liners up to pressure *P*~40÷50 GPa and measurements of perturbation amplitude with the error of ~0.1 mm, the liner flight base of ~0.3 mm.

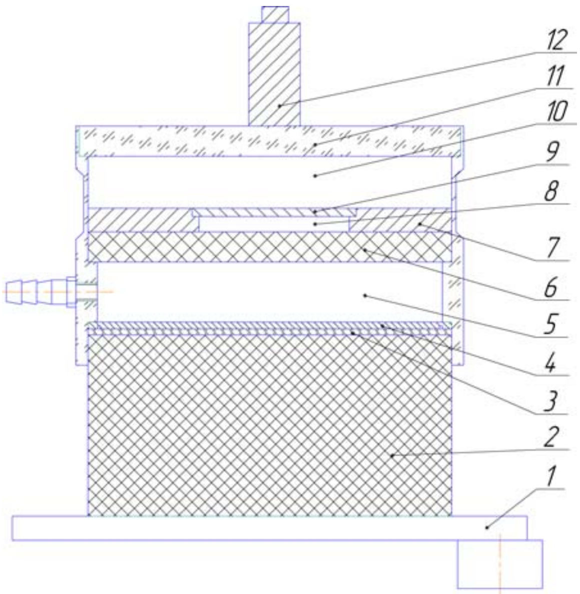
2 Results of measurements of free surface velocity of Be liner, which is accelerated by HE explosion products of second stage of loading device

To check reliability of $P(t)$ calculation, measurements of liner free surface velocity versus time were performed similar to that in work [2]. The measurements were conducted with use of Fabry-Perot laser interferometer [7].

Fig. 2.1 presents a scheme of the experimental assembly. This scheme was earlier published in works [1], [2]. The assembly is intended for measurement of the liner velocity.

Explosion products of HE charge of the first stage accelerated (through a plexiglass damper) a steel impactor, which provided the regime of overcompressed detonation in HE of the second stage. Explosion products of HE of the second stage loaded the investigated liner quasi-isentropically (without formation of shock waves). The liner flight base was 10 mm, and it was limited by a plexiglass cutoff having $\varnothing 120\times 10$ mm. When performing the test, the assembly was vacuumized to the residual pressure of 50 mm Hg.

Fabry-Perot laser interferometer was used for recording velocity of the *Be* liner free surface. The optical gauge was mounted above the geometric center of the liner free surface.



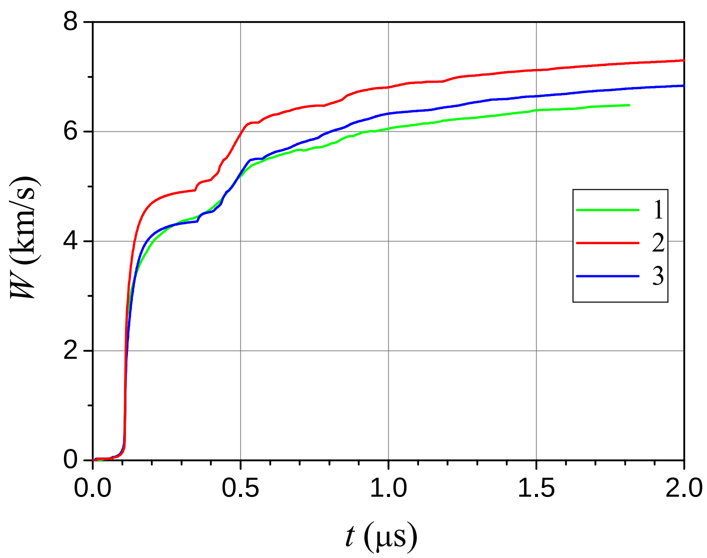
1 - generator of planar shock wave;
2 - HE of first stage: ∅90×80 mm;
3 - damper: plexiglass, ∅90×2 mm;
4 - impactor of first stage: *Fe*, ∅90×2.2 mm;
5 - vacuumized gap: δ=10 mm;
6 - HE of second stage: ∅90×10 mm;
7 - cartridge: *Al*, ∅90×4 mm;
8 - vacuumized gap: δ=2 mm;
9 - studied liner: *Be*, ∅40×2 mm;
10 - liner flight basis: *L*=10 mm;
11 - plexiglass (cutoff): ∅96×10 mm;
12 - optical gauge.

Fig. 2.1 – Experimental assembly for measurement of velocity of *Be* liner free surface.

In the «perturbation method», the relation between velocity of deterministic perturbation growth and dynamic shear strength is determined by two-dimensional numerical simulation. Here it is very important to describe reliably the liner loading regime. In particular, it is required to have utmost accurate knowledge on the dependence of pressure at the loaded surface of the liner made of the investigated material on time $P(t)$. Error in calculation of the dependence $P(t)$ causes wrong description of dynamic shear strength, which takes place in test.

Since the dependence of the liner free surface velocity on time $W(t)$ is mostly determined by pressure of explosion products on loaded surface of the investigated liner, numerical description of the experimentally measured dependence $W(t)$ provides the grounds for the statement that the dependence $P(t)$, which is not measured in the test directly, is correctly calculated as well.

It should be noted that a rather simple method is used in this work for description of the dependence $W(t)$. The method consists of selection of «losses» in the assembly energy. The essence of this calculation approach includes selection of the «instantaneous detonation» layer thickness of HE of the first stage. This artificial addition of «losses» in energy of simulated experimental scheme allows describing the pace of velocity growth in the initial part, which is the most important in the view of description of the relation $P(t)$ on the loaded surface. Therefore, a series of one-dimensional calculations, which were aimed to select the «instantaneous detonation» layer thickness of HE of the first stage, was performed for description of pace of velocity growth for the beryllium liner. Fig. 2.2 presents results of these calculations.

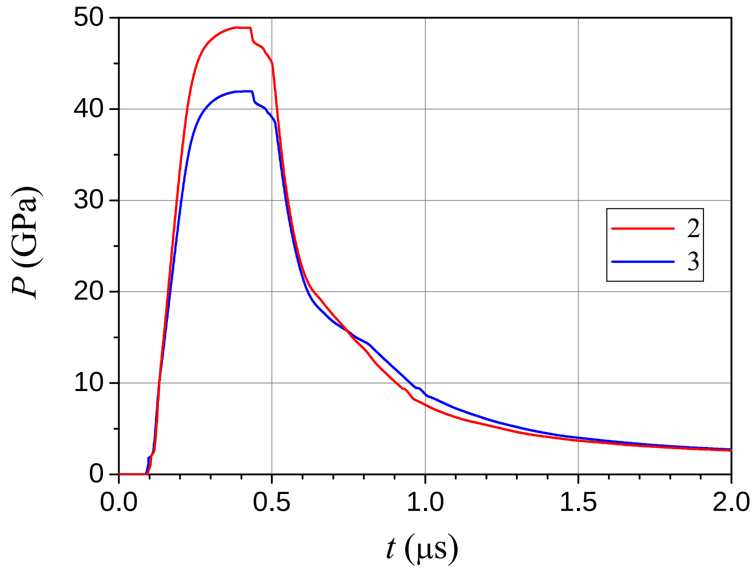


1 - test;
2 - calculation by one-dimensional Lagrange technique (without «losses»);
3 - calculation by one-dimensional Lagrange technique («losses» are 25 mm).

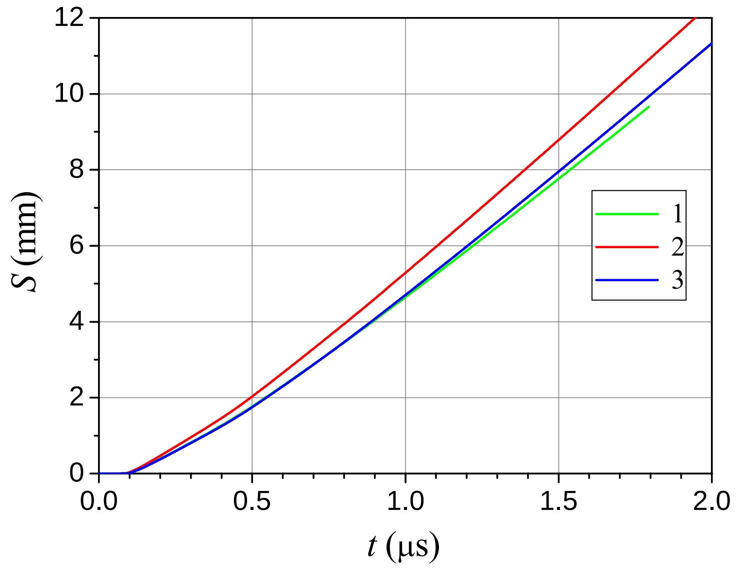
Fig. 2.2 – Results of calculations and experimental measurement of dependence $W(t)$ of *Be* liner free surface

Fig. 2.2 shows that addition of the instantaneous detonation layer ΔL=25 mm allowed to get adequate description of the liner velocity growth in the initial part of its motion. Difference in the maximum velocity values in the test and the calculation (after introducing the «losses») is ~300 m/s at the time of break of the recording.

Fig. 2.3 presents calculated dependences of pressure on the loaded surface and distance traveled by *Be* liner on time after introducing «losses» and without them.



a)



b)

1 - test;
2 - calculation by one-dimensional Lagrange technique (without «losses»);
3 - calculation by one-dimensional Lagrange technique («losses» are 25 mm).

Fig. 2.3 – Calculated dependences of pressure on loaded surface and distance traveled by *Be* liner on time after introducing «losses» and without them

At the condition of the calculated description of the obtained dependence *W(t)*, the quasi-isentropic loading regime takes place on the loaded surface of the liner (from the side of perturbations) with the maximum pressure $P \approx 42$ GPa. Error of calculated description of the liner velocity growth does not exceed 5 %.

Conclusion

In the report for Task 2 of Agreement # B590737, the possibility was demonstrated for conduction of two-frame recording of perturbations at quasi-isentropic loading of *Be* liners in the pressure range P~40÷50 GPa and for measurements of perturbation amplitude with the error of ~0.1 mm, the liner flight base of ~0.3 mm.

The report presents results of *Be* liner velocity measurements made by the laser interferometric technique. At the condition of the calculated description of the obtained dependence *W(t)*, the quasi-isentropic loading regime takes place on the loaded surface of the liner (from the side of perturbations) with the maximum pressure $P \approx 42$ GPa. Error of calculated description of the liner velocity growth does not exceed 5 %.

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